

# ***FLIGHT TECHNICAL ERROR ANALYSIS OF THE SATS HIGHER VOLUME OPERATIONS SIMULATION AND FLIGHT EXPERIMENTS***

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## **Abstract**

When instrument meteorological conditions (IMC) restrict operations to Instrument Flight Rules (IFR) at non-towered, non-radar airports, air traffic control (ATC) uses procedural separation that constrains operations to only one approaching or departing aircraft at a time – the “one-in/one-out” paradigm. The Small Aircraft Transportation System (SATS) breaks the one-in/one-out paradigm and expands capacity by allowing multiple, simultaneous operations while achieving a level of safety equal to today’s system. The concept that achieves this goal is SATS “Higher Volume Operations” (HVO). Characteristic to SATS HVO is the establishment of a Self-Controlled Area (SCA), which would be activated by ATC around designated non-towered, non-radar airports. During periods of poor visibility, SATS pilots would take responsibility for separation assurance between their aircraft and other similarly equipped aircraft in the SCA. Using onboard equipment and simple instrument flight procedures, they would then be better able to approach and land at the airport or depart from it. This concept would also require a new, ground-based automation system, the Airport Management Module (AMM) typically located at the airport that would provide appropriate sequencing information to the arriving aircraft.

This paper provides an analysis of Flight Technical Error (FTE) from recent SATS experiments, called the Higher Volume Operations (HVO) Simulation and Flight experiments, which NASA conducted to determine pilot acceptability of the HVO concept for normal operating conditions. Reported are FTE results from simulation and flight experiment data indicating the SATS HVO concept is viable and acceptable to low-time instrument rated pilots when compared with today’s system (baseline). Described is the comparative FTE analysis of lateral, vertical, and airspeed deviations from the baseline and SATS HVO experimental flight procedures. Based on FTE analysis, all evaluation subjects, low-time instrument-rated pilots, flew the HVO procedures safely and proficiently in comparison to today’s system. In all cases, the results of the flight experiment validated the results of the simulation experiment and confirm the utility of the simulation platform for comparative Human in the Loop (HITL) studies of SATS HVO and Baseline operations.

## **Introduction**

Americans have come to depend on the United States’ National Airspace System (NAS) for the efficient and rapid movement of people, goods, and services. In 2000, more than 670 billion revenue passenger miles were flown [1]. Commercial air transport service has become so important that any major disturbance in its service is met by public outcry.

While the current system of hub and spoke operations has served its purpose well, it is beginning to reach a capacity plateau. Due to the increasing demand on the system and with only modest potential gains in the number of flights, the system will reach gridlock within the next 10-15 years [1,2]. Additionally, most airlines use the more economical hub and spoke system which causes people to travel significantly farther or longer to get to their destination. Nearly 70% of domestic air travelers are forced to fly through fewer than 35 of the United States’ more than 18,000 landing facilities. These intermediate stops and layovers dramatically increase a traveler’s overall door-to-door trip time. The rising success of air carriers and air charter services that specifically target more point-to-point travel provides evidence that people and businesses are seeking greater mobility through more convenient alternatives for air service [3].

Through the Small Aircraft Transportation System (SATS) Project, NASA, the FAA, and the National Consortium for Aviation Mobility have been exploring the feasibility of increasing personal mobility and system capacity by expanding access to thousands of underutilized smaller airports across the United States. Many of these airports lack control towers and lie outside air traffic control (ATC) radar coverage, but do provide a unique potential for convenient access to small cities and business communities. New, small, efficient aircraft being developed by companies such as Honda, Avocet, Cessna, Diamond, Eclipse, Safire, Cirrus,

Lancair, Adam Aircraft, and others are touted to provide point-to-point air-charter service and make use of these small airports. Several air charter businesses are planning to use these new aircraft to provide their customers with point-to-point service.

When instrument meteorological conditions (IMC) restricts operations to Instrument Flight Rules (IFR) at non-towered, non-radar airports, ATC uses procedural separation that restricts operations to only one approaching or departing aircraft at a time – the “one-in/one-out” paradigm. While procedural separation is safe, it severely limits the operational throughput at these airports. Air charter operators might be compelled to use these airfields if the IMC operational efficiency can be improved. SATS breaks the one-in/one-out paradigm and expands capacity by allowing multiple, simultaneous operations while achieving a level of safety equal to today’s system. The concept of operations (CONOPS) that achieves this goal is termed SATS “Higher Volume Operations” (HVO).

## SATS HVO CONOPS Overview

Key to this concept is the use of a newly defined area of flight operations called a Self-Controlled Area (SCA), established during periods of IMC around “SATS designated airports” (i.e., non-towered, non-radar airports). This concept is based on a distributed decision-making environment that assumes the majority of the decision-making responsibility would remain with the pilot because it would provide pilots with the necessary procedures, tools, and information to enable safe operations within the SCA.

Within the SCA, pilots, using advanced airborne systems, would have the ability and responsibility to maintain separation between themselves and other similarly equipped airplanes. Aircraft operating in this airspace would need special avionics, e.g., automated dependent surveillance-broadcast (ADS-B), a two-way data link, and appropriate self-separation tools in order to participate. This concept would also require a new, ground-based automation system, the airport management module (AMM), typically located at the airport that would provide appropriate sequencing information to the arriving aircraft. The AMM provides an arrival sequence and broadcasts

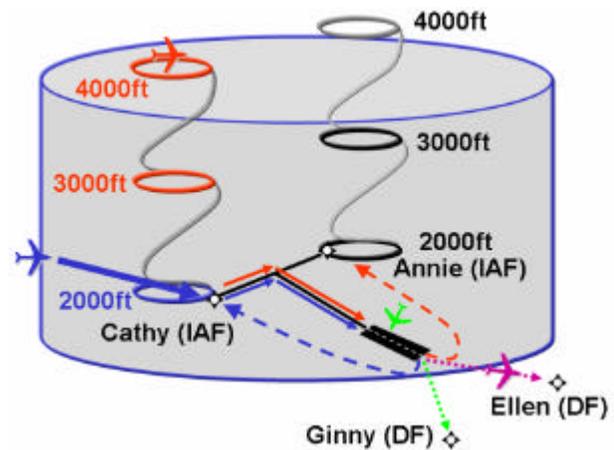
the total number of arriving aircraft in the SCA. It does not, however, provide separation, altitude assignments, or sequence departures.

This proposed operational concept emphasizes the integration with the current and planned near-term NAS. Additionally, the focus of the underlying design approach was on simplicity from both a procedural and a systems requirements standpoint. It was also assumed that any additional ATC workload must be minimized, and enroute procedures must be compatible with today’s ATC system.

A joint NASA Langley Research Center and FAA Technical Center simulation study focused on the SATS HVO and ATC transitions (i.e., SCA airspace design, and controller-pilot SCA transition procedures) to ensure that additional ATC workload is minimized and that SATS HVO integrates with today’s ATC system. Controller acceptance of HVO has been positive [9].

The SATS HVO concept is a starting point or “template” for additional designs and analyses. To date, the development focus has been on providing an operational concept that was safe, would enable more than one operation at a time, and would not require significant ground infrastructure costs or improvements.

GPS-T instrument approach procedures were chosen as a basis for this concept, although other instrument approach procedures could be used.



**Figure 1. SATS HVO Example**

Many of the features of the GPS-T based SATS HVO concept are depicted in Figure 1.

SATS arrivals (**Red** and **Blue** aircraft) to the Initial Approach Fixes (IAFs) with alternating missed approaches, and departures (**Green** and **Purple** aircraft) to the Departure Fixes (DFs) are depicted in a “snapshot” in time:

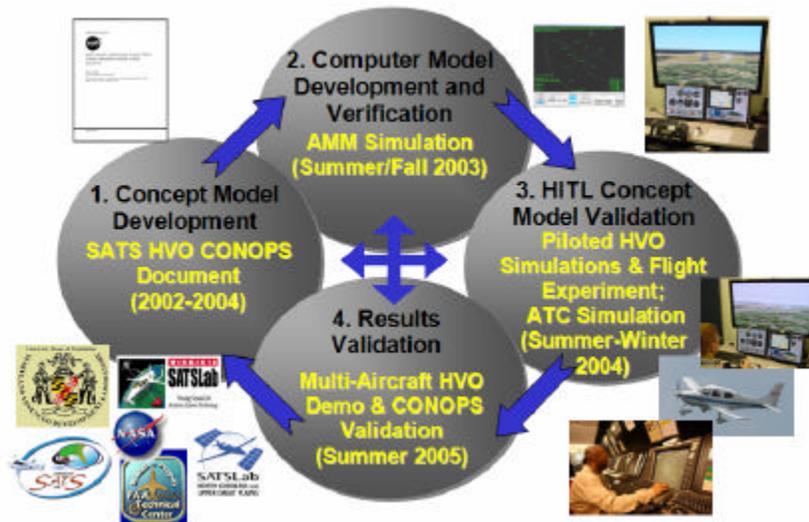
- **Blue** – entering the SCA having coordinated descent with ATC because the AMM provided: “lateral entry (no other aircraft assigned to Cathy), follow none, missed approach Cathy” (missed approach depicted as blue dashed path),
- **Red** – having arrived by IFR clearance to the transition fix at 4000ft, the AMM provided: “vertical entry (3000ft at Cathy is open), follow blue aircraft, missed approach to Annie,” (missed approach depicted as red dashed path)
- **Purple** – departing SCA via departure procedure and contacting ATC,
- **Green** – released by ATC to depart; holding short and using on-board tools to find open slot in arrival stream to take the active runway and depart.

Aircraft arriving into the SATS airport will be under ATC clearance according to an IFR flight plan to a transition fix above the SCA. The transition fix is also the initial approach fix on a GPS-T instrument approach procedure. Prior to reaching the transition fix, the pilot would request a landing assignment from the AMM. The AMM responds with the SCA entry procedure (standby, vertical or lateral), relative sequence information (follow <Callsign>), and missed approach hold fix assignment (Annie or Cathy). The AMM only tracks arrivals and missed approach aircraft, not departures, and thereby allows up to four arriving aircraft in the SCA before denying entry (issuing a “standby”). Based on sequence info, and following

the HVO procedure to “descend to lowest available altitude,” pilots are deconflicted from up to three other arriving aircraft (i.e., the AMM reserves space for up to four aircraft at the IAFs).

Pilots given a “standby” sequence can track the number of aircraft in the SCA to estimate their delay as they continue to their clearance limit and establish a standard hold above the SCA at the transition fix. When the pilot gets an AMM entry message with sequence and missed approach information, the pilot is assured an opening at 3000ft and will request descent from ATC. The pilot can then determine if further descent to the 2000ft hold is prudent by following the “lowest available altitude” procedure at the IAF, (clearing for traffic below is the pilot’s self-separation responsibility in the SCA). A missed approach hold slot is also guaranteed by the AMM, so a pilot going missed would then climb to the “lowest available altitude” back at the IAF and would then be sent a new arrival sequence.

Pilots will initiate their approach once adequate spacing behind the lead aircraft has been met (determined through either a generic rule-based spacing procedure, i.e., safe for all combinations of aircraft performance, or by using an on-board self-spacing tool). For SATS departures, pilots will file flight plans with a SATS departure procedure to a departure fix (DF, i.e., Figure 1 Ellen or Ginny), obtain ATC clearance, and then use on-board information/tools to find a departure window, e.g., allowed to depart if there are no arriving aircraft within 5nm of the airport. The pilot would then depart and contact ATC according to the departure procedure.



**Figure 2. HVO Validation**

## HVO CONOPS Validation

The SATS HVO CONOPS [4] was developed through a four phase, building block research process depicted in Figure 2.

Phase one shows the CONOPS growing out of a need for developing the HVO “concept model” and documenting it. The key safety properties of a draft HVO CONOPS were also established by a mathematical verification method based on formal logic and theorem proving [5]. This study began formally verifying that self-separation is maintained when pilots adhere to the CONOPS procedures (including AMM logic).

Phase two involved the development of a simulation environment (computer model) that included the AMM. The AMM was verified by testing its accurate function during a representative set of HVO scenarios.

Phase three includes the bulk of the SATS HVO experimental work in validating the SATS HVO CONOPS (concept model) through human in the loop (HITL) studies. The HVO flight experiment was flown to validate pilot acceptability of a subset of the HVO simulation scenarios. Also, the ATC simulation study focused on determining controller acceptability of the concept model was completed in December 2004 [9].

Phase four was a proof-of-concept public demonstration of six SATSLab aircraft flying the

SATS HVO CONOPS procedures in the 2005 SATS Technology Demonstration held in Danville, Virginia.

All four phases provided feedback to the improvement of the SATS HVO CONOPS and ultimately toward recommending a viable way to improve upon the one-in/one-out procedure in place in the NAS today.

## HVO Simulation and Flight Experiments

Determining pilot acceptability of HVO meant investigating research objectives through a piloted simulation and a subsequent flight experiment:

Comparing the SATS HVO CONOPS to the one-in-one-out procedural control environment available today (Baseline)...

- Can pilots safely and proficiently fly the airplane while performing SATS HVO procedures?
- Do pilots perceive that workload, while using HVO procedures and tools, is no greater than flying in today’s system?

The analysis of flight technical error (FTE) data summarized in this paper compliments qualitative subject pilot assessments of their own workload, situation awareness, and HVO usability. Based on this FTE analysis, all evaluation subjects,

low-time instrument-rated pilots, flew the HVO procedures safely and proficiently in comparison to today's system. FTE data were collected during the piloted HVO simulation and flight experiments completed in the summer of 2004. The HVO flight experiment was flown to validate pilot acceptability of a subset of the HVO simulation scenarios. A common pool of pilots was used. Fifteen pilots flew the HVO Simulation Experiment, and 12 of those pilots flew the HVO Flight Experiment. This reduced training requirements for the HVO Flight Experiment and allowed pilots to progress logically from hand-flying a medium fidelity general aviation (GA) simulator to the Cirrus SR22 aircraft.

**Hypotheses**

**Flight Technical Error** (Baseline & SATS scenarios) – the subject of this paper

- Subject pilots will fly within the FAA's Practical Test Standards (PTS) for the instrument rating 100% of the time during all scenarios
- Deviations from assigned flight paths (i.e., RMSE values) will be equivalent across all scenarios

**Subjective Workload** (Baseline & SATS scenarios) – reported in references [6-8]

- Equivalent workload ratings will be associated with all scenarios

**Situation Awareness** (Baseline & SATS scenarios) reported in references [6-8]

- Equivalent situation awareness ratings will be associated with all scenarios

**Procedure Conformance Monitoring** (SATS scenarios only) reported in references [6-8]

- Subject pilots will fly within conformance of the SATS HVO procedures 100% of the time

**Experiment Design and Procedure**

The experiment design matrix shown in Figure 3 includes the five scenarios flown in the simulation. Three of these scenarios were repeated in the flight experiment. For the simulation experiment the experiment design used for data

collection was a 2 (Procedure Type) x 5 (Scenario Type), within-subject design in which the same 15 participants (i.e., low time instrument rated pilots) were assigned to each experimental cell (i.e., test condition). Simulation subject pilots 1 through 15 (S<sub>1-15</sub>) were asked to perform all 10 test conditions in partially counterbalanced order under simulated IMC. For the flight experiment, a 2 (Procedure Type) x 3 (Scenario Type), within-subject design was used for data collection and 12 of the same 15 subject pilots (F<sub>1-12</sub>) performed six test conditions twice in partially counterbalanced order under simulated IMC. Dependent measures included pilot FTE and subjective assessments of workload and situation awareness.

		PROCEDURE TYPE	
		Baseline	SATS
SCENARIO TYPE	Departure	S <sub>1-15</sub>	S <sub>1-15</sub>
	Approach Without Traffic	S <sub>1-15</sub> F <sub>1-12</sub>	S <sub>1-15</sub> F <sub>1-12</sub>
	Approach With Virtual Traffic	S <sub>1-15</sub> F <sub>1-12</sub>	S <sub>1-15</sub> F <sub>1-12</sub>
	Approach to Missed Approach with Virtual Traffic	S <sub>1-15</sub> F <sub>1-12</sub>	S <sub>1-15</sub> F <sub>1-12</sub>
	Approach with Piloted Traffic (Linked Simulation)	S <sub>1-15</sub>	S <sub>1-15</sub>

S=Simulation Subjects  
F= Flight Subjects

**Figure 3. Experiment Design Matrix**

**Scenarios**

The HVO experiments were designed to represent the HVO CONOPS through a sample set of scenarios:

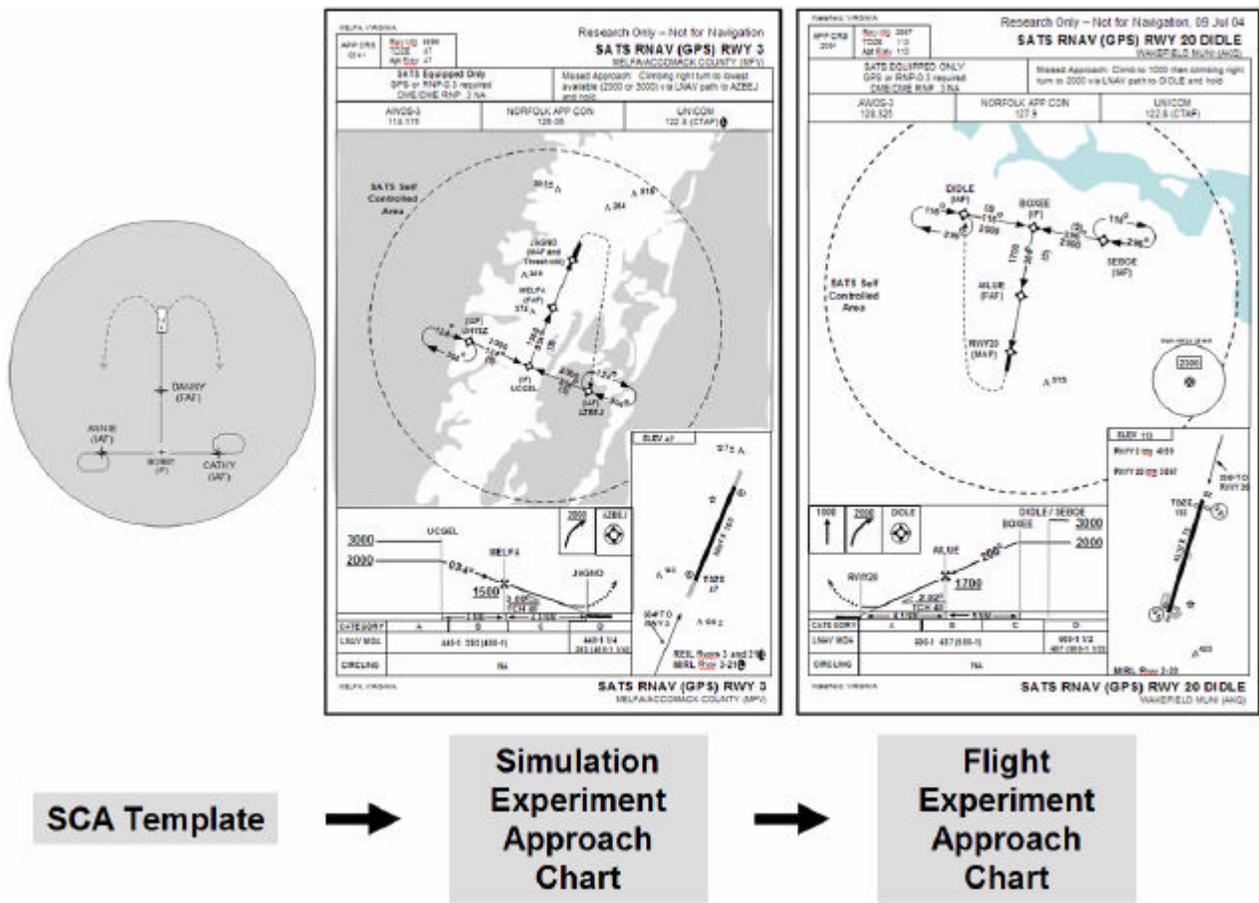
- **Departure with approaching traffic** – this scenario was flown in the simulation experiment only. The pilot task was to receive an ATC clearance, taxi onto the active runway, takeoff, and depart the airfield. In Baseline scenarios, ATC waited to give departure clearance to the subject pilot's aircraft until an approaching aircraft had landed and canceled its clearance. In HVO, the pilot was to self-determine when to depart by finding an opening in the approach traffic flow. This was done by the pilot using a traffic display that showed aircraft on the approach and as long as the approaching aircraft was beyond the final approach fix (FAF), a departure was allowed. The durations of the SATS scenarios were about half as long as the durations of the Baseline scenarios.

- **Approach without traffic** (no holding required). The pilot task was to descend and fly the approach via ATC clearance during the Baseline scenarios. During the SATS scenarios, the pilot requested and received a “lateral entry, follow none” sequence from the AMM, was handed off into the SCA from ATC, and self-initiated the approach. Typically the durations of the SATS scenarios were equivalent to those of the Baseline scenarios.
- **Approach with virtual traffic** (holding required). This scenario clearly differentiated Baseline from HVO. In Baseline, the pilot waited behind two other aircraft in holding until they had landed and ATC provided clearance to begin the approach (i.e., 30+ minutes in holding). In HVO, the pilot followed the AMM sequencing behind the two other aircraft, self-separated from the other aircraft in the SCA, and self-initiated the approach by following advisories provided by a self-spacing software tool. The SATS scenarios’ durations were about half that of the Baseline scenarios.
- **Approach to missed approach with virtual traffic** (holding required). This scenario included having the pilot fly the missed approach. SATS scenarios required flying the missed approach while self-separating in the SCA. The SATS scenarios’ durations were

about two-thirds as long as the Baseline scenarios’ durations.

- **Multi-pilot linked simulation approaches** (holding required). This scenario was flown with four linked simulators to verify the HVO concept by introducing the variability of individually flown aircraft (instead of using one pilot in a scenario with precisely flown virtual traffic). The goal was to determine if pilots could conduct HVO while serving as traffic for one another. Flown only in the medium fidelity simulation, pilots accomplished this task safely and proficiently. The time required to complete a multi-pilot HVO scenario was about one-quarter to one-third of the duration of a Baseline scenario.

The experimental scenario flight profiles were based on GPS-T instrument approach procedures. Figure 4 depicts the progressive development of the experiment flight profile that began with the template SCA in the CONOPS and was implemented as shown in the simulation and flight approach charts. Subject pilots used these to fly experiment scenarios (Baseline charts not shown). The approach chart is a key element of the pilot procedures and coupled with task training, all evaluation pilots were able to fly the HVO procedures (described earlier with Figure 1) and the accompanying non-precision GPS-T instrument flight approach procedure.



**Figure 4. HVO Procedure Development Progression -- Concept to Flight Experiment**

**Subject Pilots and Training**

In choosing a subject pool to validate the HVO concept, researchers identified criteria for a pool of pilots who were capable, but not overly experienced. Although not tested, it is inferred that if the low-time instrument rated subject pool validated the concept positively (as was expected), then more experienced pilots would do the same. Subject pilot criteria were established to select low-time (less than 1000 flight hours) instrument rated pilots who were current to fly in IFR. None of the participants had previously flown a Cirrus SR22 aircraft, worked as a flight crewmember for an air carrier within the last year, or flown for the military.

A building block approach was employed to prepare subject pilots to accomplish the experiment tasks. This meant they manually flew the scenarios in simulated IMC using traditional round-dial instruments for primary flight guidance information (i.e., without autopilot). Advisory information was

provided through a research multi-function display (MFD) that included a moving map with navigation information and traffic depiction. For the SATS scenarios, AMM sequence info, and procedure support information was also included on the MFD. Before the simulation experiment, subject pilots were first oriented to the HVO concept; and then they were given a session of hands-on simulator training to learn the simulator performance and controls. The research MFD interface required focused training to orient the subjects to its functionality and operation. Subjects were then given a more in-depth HVO research display training session that fully prepared them for the task of flying both Baseline and SATS scenarios. Through debriefing comments, all subject pilots agreed their training was adequate to perform simulation experiment tasks.

To train pilots for the flight experiment, they were provided an electronic read-ahead training briefing before arrival and were given a 1 hour

training session that reviewed the briefing and provided them a hands-on simulator session to re-familiarize them with the experiment tasks. Orientation to the Cirrus SR22 was conducted by the safety pilot (a certified Cirrus instructor) on the ground and in flight. In flight training included aircraft basic instrument maneuver training and two practice GPS instrument approaches before data runs began. Through debriefing comments, all subject pilots agreed that their training was adequate to perform flight experiment tasks.

### Experiment Platform and Profiles

Figure 5 shows the GA simulator and the Cirrus SR22's instrument panel used for the

experiments. The simulator was a building block interface for the aircraft, and both used common research software to drive the MFD and the Horizontal Situation Indicator (HSI). Variation between the simulation and flight profiles was also deliberately minimized so as not to alter the experiment objectives or hypotheses. Pilot tasks (manual flight of arrival, holding, non-precision approach with respect to target airspeed, altitude, and lateral path) were to different target values for the simulation and flight, but in both cases pilots were tasked to meet instrument PTS criteria.



**Figure 5. HVO Experiment Platform Progression (note commonality of HSI and MFD)**

### FTE Data Analysis

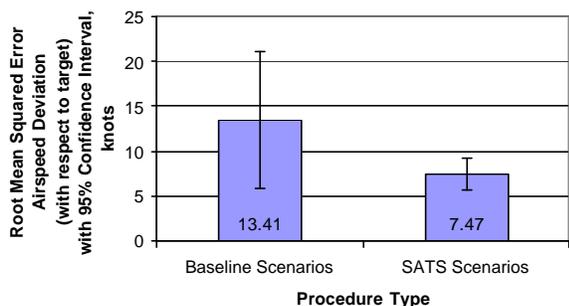
Airspeed, altitude and lateral path deviation were measured during the experiments to assess the FTE of pilots flying Baseline and SATS approach scenarios (departure scenarios were not assessed by FTE measures). Their task objective was to fly the scenario while maintaining IFR PTS criteria [10]. FTE was measured as performance error from that task objective. Data were analyzed by way of repeated measures Analysis of Variance (ANOVA) tests, with the main effect of procedure type being of primary interest, and a 5-percent significance level (i.e.,  $p = 0.05$ ) for the statistical analyses was set a priori [11].

While the hypothesis that subject pilots would “maintain all scenarios” was not supported, the viability and acceptability of the SATS HVO concept is not diminished because in all cases the second hypothesis that “deviations from assigned flight paths (i.e., RMSE values) would be equivalent across all scenarios” was supported by the FTE results. In all cases, the pilots’ FTEs that occurred while flying SATS scenarios were not greater than the FTE’s that occurred while flying Baseline scenarios. In some cases, it was found through a statistical analysis of FTE data that their FTE during the SATS scenarios was significantly smaller (i.e., better) than during the Baseline scenarios.

### Root Mean Squared Error (RMSE) with respect to Airspeed Target on the approach

Pilots were instructed to fly the same target airspeeds for both the SATS and Baseline scenarios. Target airspeeds were chosen for the three segments of the GPS-T non-precision instrument approach procedure: initial (IAF to Intermediate Fix or IF); intermediate (IF to Final Approach Fix or FAF), and final (FAF to Missed Approach Point or MAP). The target airspeeds for the initial, intermediate and final segments were 110, 100 and 95 knots, respectively for the simulation experiment. The flight experiment used 120, 110, and 100 as target airspeeds. The different speeds were chosen for the flight experiment by the safety pilot to ensure better aircraft performance. Instrument rating PTS requires the pilot maintain +/- 10 knots of the target airspeed [10].

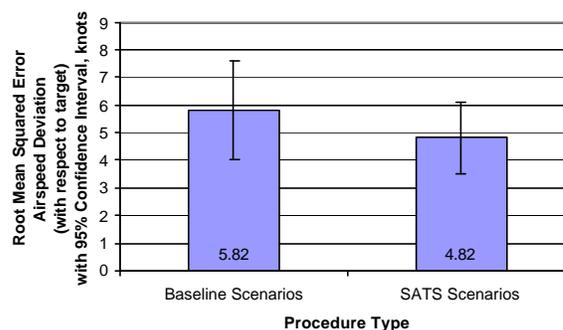
A significant difference was found to exist between the airspeed target RMSE values associated with each procedure type in the simulation experiment ( $p = 0.001$ ). A RMSE airspeed deviation of 13.41 knots occurred during the Baseline scenarios [Mean (M) = 13.41, Standard Deviation (SD) = 7.65, Sample Size (N) = 60], and a RMSE airspeed deviation of 7.47 knots occurred during the SATS scenarios (M = 7.47, SD = 1.79, N = 60).



**Figure 6. Simulation Experiment Deviation from Airspeed Target**

This finding shown in figure 6 indicates that in the simulation experiment, subject pilots maintained airspeed with respect to an assigned target value more accurately when they performed the SATS scenarios than when they performed the Baseline scenarios.

A significant difference was also found to exist between the airspeed target RMSE values associated with each procedure type in the flight experiment ( $p = 0.003$ ). A RMSE airspeed deviation of 5.82 knots occurred during the Baseline scenarios (M = 5.82, SD = 1.81, N = 72), and a RMSE airspeed deviation of 4.82 knots occurred during the SATS scenarios (M = 4.82, SD = 1.29, N = 72).



**Figure 7. Flight Experiment Deviation from Airspeed Target**

This finding illustrated in figure 7 indicates that subject pilots maintained airspeed with respect to an assigned target value more accurately when they performed the SATS scenarios than when they performed the Baseline scenarios.

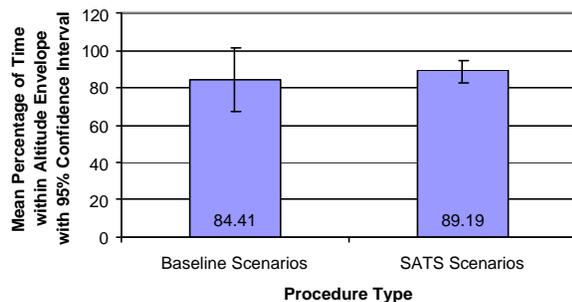
### Airspeed FTE simulation-to-flight

**conclusion:** While the hypothesis that subject pilots would fly within the FAA’s PTS for the instrument rating 100% of the time during all scenarios was not supported by the airspeed target RMSE values collected during in the simulation experiment, the viability and acceptability of the SATS HVO concept is not diminished because the second hypothesis was supported in both of the experiments. Coupling the findings of the simulation and flight experiments indicates similar results for both experiments. Specifically, subject pilots maintained airspeed with respect to an assigned target value more accurately when they performed the SATS scenarios than when they performed the Baseline scenarios. Therefore, the results of the flight experiment validate the simulation experiment’s results.

### Percent time within Altitude Envelope on the approach

Pilots were instructed to fly within the same PTS altitude envelope for both the Baseline and SATS scenarios: -100 ft of “at or above” altitudes, and +100 and -0ft for the Minimum Descent Altitude (MDA) until MAP or visual transition to landing [10].

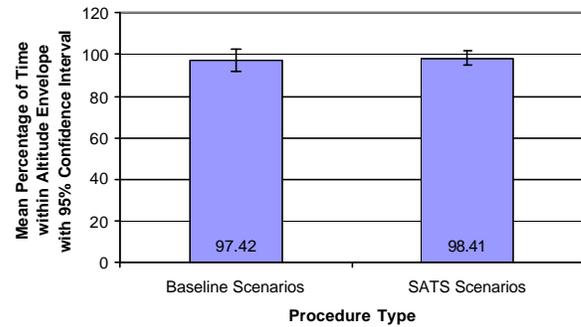
No significant difference was found to exist between the percentages of time within altitude envelope associated with each procedure type in the simulation experiment ( $p = 0.141$ ). During the Baseline scenarios, subject pilots flew within the defined altitude envelope 84.41% of the time ( $M = 84.41$ ,  $SD = 17.61$ ,  $N = 60$ ). During the SATS scenarios, subjects flew within the defined altitude envelope 89.19% of the time ( $M = 89.19$ ,  $SD = 5.98$ ,  $N = 60$ ).



**Figure 8. Simulation Experiment Percent Time in Altitude Envelope**

This finding shown in figure 8 indicates that in the simulation experiment subject pilots maintained altitude within an assigned envelope equally well when they performed the Baseline scenarios and when they performed the SATS scenarios.

In the flight experiment, no significant difference was found to exist between the percentages of time within altitude envelope associated with each procedure type ( $p = 0.300$ ). During the baseline scenarios, subject pilots flew within the defined altitude envelope 97.42% of the time ( $M = 97.42$ ,  $SD = 5.44$ ,  $N = 72$ ). During the SATS scenarios, subject pilots flew within the defined altitude envelope 98.41% of the time ( $M = 98.41$ ,  $SD = 3.58$ ,  $N = 72$ ).



**Figure 9. Flight Experiment Percent Time in Altitude Envelope**

This finding illustrated in figure 9 indicates that in the flight experiment subject pilots maintained altitude within an assigned envelope equally well when they performed the baseline scenarios and when they performed the SATS scenarios.

### Altitude FTE simulation-to-flight

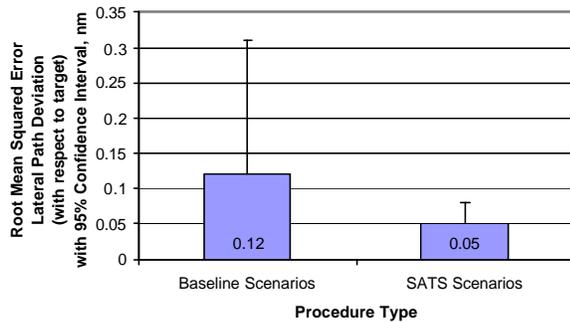
**conclusion:** Coupling the findings of the simulation and flight experiments indicates similar results for both experiments. The first FTE hypothesis that subject pilots would maintain instrument PTS 100% of the time was not supported in both experiments, but the second hypothesis was supported in both experiments. Specifically, subject pilots maintained altitude with respect to an assigned target value equally well when they performed the SATS scenarios and when they performed the Baseline scenarios. Therefore, the results of the flight experiment validate the results of the simulation experiment.

### RMSE with respect to Lateral Path Target on the approach

Pilots were instructed to use target path as approach flight path during both the Baseline and SATS scenarios. Instrument PTS is to maintain within  $\frac{3}{4}$  scale deflection of the course deviation indicator (CDI) [10]. Full scale deflection on the research HSI represented .3 nautical miles through the approach procedure.

A significant difference was found to exist between the lateral path deviation RMSE values associated with each procedure type in the simulation experiment ( $p = 0.037$ ). A RMSE lateral path deviation of 0.12 nautical miles (nm) occurred during the Baseline scenarios ( $M = 0.12$ ,  $SD = 0.19$ ,

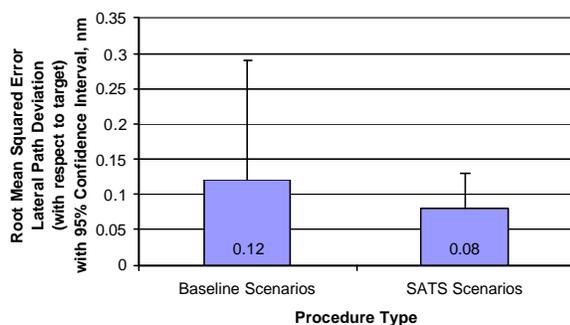
N = 60), and a RMSE lateral path deviation of 0.05 nm occurred during the SATS scenarios (M = 0.05, SD = 0.03, N = 60).



**Figure 10. Simulation Experiment Deviation from Lateral Path Target**

This finding shown in figure 10 indicates that subject pilots maintained lateral path deviation with respect to an assigned target value more accurately when they performed SATS scenarios in the simulation experiment.

In the flight experiment, a significant difference was found to exist between the lateral path deviation target RMSE values associated with each procedure type ( $p = 0.045$ ). A RMSE lateral path deviation of 0.12 nm occurred during the baseline scenarios (M = 0.12, SD = 0.17, N = 72), and a RMSE lateral path deviation of 0.08 nm occurred during the SATS scenarios (M = 0.08, SD = 0.05, N = 72).



**Figure 11. Flight Experiment Deviation from Lateral Path Target**

This finding as shown in figure 11 indicates that in the flight experiment, subject pilots maintained lateral path deviation with respect to an

assigned target value more accurately when they performed the SATS scenarios than when they performed the baseline scenarios.

#### Lateral Path FTE simulation-to-flight

**conclusion:** Coupling the findings of the simulation and flight experiments indicates similar results for both experiments supporting both hypotheses. The first hypothesis that pilots would maintain instrument PTS 100% of the time was supported as was the second hypothesis that deviations would be equivalent across all scenarios. Specifically, subject pilots maintained lateral path with respect to an assigned target path more accurately when they performed the SATS scenarios than when they performed the Baseline scenarios. Therefore, the results of the flight experiment validate the results of the simulation experiment.

#### Conclusion:

This paper provides an analysis of Flight Technical Error (FTE) from recent SATS experiments, called the Higher Volume Operations (HVO) Simulation and Flight experiments, which NASA conducted to determine pilot acceptability of the HVO concept for normal operating conditions. Reported are FTE results from simulation and flight experiment data indicating that the SATS HVO concept is viable and acceptable to low-time instrument rated pilots when compared with today's system (Baseline). Described is the comparative FTE analysis of lateral, vertical, and airspeed deviations from the baseline and SATS HVO experimental flight procedures.

Based on FTE analysis, all evaluation subjects, low-time instrument-rated pilots, flew the HVO procedures safely and proficiently in comparison to today's system. Specifically, subject pilots maintained airspeed and lateral path more accurately when they performed the SATS scenarios than when they performed the Baseline scenarios. Subjects maintained altitude equally well in both SATS and Baseline scenarios. In all cases, the results of the flight experiment validated the results of the simulation experiment and confirm the utility of the simulation platform for comparative HITL studies of SATS HVO and Baseline operations.

The piloted experiments described in this paper were part of the building-block validation and verification process of the SATS HVO CONOPS that included multiple elements ranging from formal analysis of the procedures to flight test, to full-system architecture prototype that was successfully shown to the public at the June 2005 SATS Technical Demonstration in Danville, VA.

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